Status report to the North Dakota Oil and Gas Research Program
Program
Task 1 – Modeling
Contract G-038-075
"New Technologies for Safe and Cost Effective Oil Conditioning in North Dakota"

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11/1/2016
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Executive Summary

Statoil has put together a comprehensive team comprising of members from research and operations with a solemn intent to find field solutions that will improve our ability to produce crude oil in compliance with North Dakota Industrial Commission's (NDIC) recent vapor pressure requirements. Task 1 for this project comprises of process modeling; results for which are presented in this report.

The primary objective of the process modeling task is to envisage the underlying mechanism associated with the evolution of light ends from the well head to tank storage. It is important to understand the expected vapor pressure and phase behaviors throughout the oil conditioning process in order to identify the root causes that lead to these challenges. The project team has used Honeywell's UniSim® Design Suite R443 tool for modeling and simulation. Honeywell's UniSim® Design Suite is a process modeling software that provides steady state and dynamic process simulation in an integrated environment.

The NDIC's order 25417 regarding the conditioning of crude oil requires gas-liquid separators and/or emulsion heater treaters to operate at a pressure of no more than 50 psi and a temperature of no less than 110°F. This order mandates a vapor pressure of crude oil ($VPCR_4$) transportation of 13.7 psi using ASTM D6377 standard. ASTM D6377 is an updated standard similar to ASTM D323 which includes advances in measurement technology. The test method ASTM D323 is used to determine the Reid vapor pressure (RVP) of a substance as a common measure of volatility. RVP is defined as the vapor pressure exerted by a liquid at 100°F (37.8°C). The reported vapor pressure values in this study assume the ASTM D323-08 standard.

Once the base case of the process model was established and validated, the study team established some sensitivities in order to understand the effect of various process unit operations on crude vapor pressures. Sensitivity analyses included: (i) effect of heater treater pressure and temperature on crude vapor pressure; and (ii) effect of separator pressure on crude vapor pressure.

Modeling completed in this study suggests that heater treaters are adequate devices to control the vapor pressure of crude oil in North Dakota. Heater treaters are the most common device used in North Dakota for conditioning of crude oil. The unit functions to complete a three phase separation of gas, oil, and water. Heat is applied to improve the efficiency of separation, and to help break oil-water emulsions. The operating conditions of the heater treater affect the vapor pressure of the crude oil. The modeling results provide a relative comparison of operating pressure and temperature relative to RVP of crude oil. The results indicate that there can be a wide range of performance for heater treaters over their operating range. A RVP of 5 to 14 psi for crude oil is possible over operating temperature ranges from 90 to 150°F, and pressure ranges from 15 to 25 psi.

Although heater treaters can theoretically achieve a range of RVP within the NDIC requirements, wind, cold weather, and storage can present additional challenges. The modeling results help to understand the expected performance of heater treaters and enable the diagnosis of performance issues that may be evident from field sampling of crude oil vapor pressure. This is a first step in understanding the expected vapor pressure measurements from the field. Based on these results, we may be able to identify some unique opportunities for technology to remove additional light ends based on the expected concentrations. Maturing our understanding surrounding these mechanisms may elucidate simple solutions.

Acronyms, Abbreviations and Units

Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
EoS	Equation of State
LACT	Lease Automatic Custody Transfer
NDIC	North Dakota Industrial Commission
PR	Peng-Robinson
SRK	Soave-Redlich-Kwong
VP	Vapor Pressure
VPCR	Vapor Pressure of Crude oil

Units

°C	Degree Celsius
°F	Degree Fahrenheit
atm	Atmosphere
bbld	Barrels per day
mcfd	Thousand cubic feet per day
psi	Pounds per square inch

1   Background

On April 1st 2015, order 25417 by the North Dakota Industrial Commission (NDIC) went into effect that requires all producers to install and utilize oil conditioning equipment to significantly reduce the vapor pressure of Bakken crude oil. Although a high percentage of compliance has been achieved by the industry, these efforts have brought on additional costs, and operation during cold and inclement conditions continue to be a challenge. Compliance with the order for the first time this winter has provided the field experience to pinpoint a number of operational issues. This project is exploring cost effective robust technology solutions that can be implemented early to improve safe operations, manage operational costs, and continue compliance with the crude oil conditioning order.

The oil conditioning order 25417 was written as a matter of safety. Rail accidents across the country drew attention to how Bakken oil is produced and processed at the well site. The order represents a congruence of a significant volume of testimony for how to make processing and transport as safe as possible. The order is based on science from the testimony received. National standards recognize oil with a Vapor Pressure of 14.7 psi or less to be stable, and the goal in North Dakota is to produce crude oil that does not exceed a measured vapor pressure of 13.7 psi, which allows for a one psi error in the sampling procedures and measurement equipment.

The goal of this project is to provide technical solutions that address challenges relative to meeting vapor pressure requirements for Bakken crude oil. Specific objectives are as follows:
- Provide a technical and scientific understanding of vapor pressure behavior in oil conditioning operations through modeling - treating and storage equipment
- Improve the reliability and decrease the cost of crude oil conditioning at the wellhead by investigating the feasibility for sonic separation
- Decrease the costs associated for conditioning high RVP crude oil by investigating chemical treatment options.

2   Introduction to oil and gas facilities design

Oil and gas processing facilities are designed to:
- Separate the oil, gas, water, and solids
- Treat the oil to meet sales specifications (e.g., BS&W, salt content, vapor pressure)
- Measure and sample the oil to determine its value
- Deliver product to the transportation system (i.e., the pipeline, truck, or railcar).

The first step in the process is separating the gas from the liquid and the water from the oil. Typically, a pressure vessel is used to first separate gas from the other liquids and at a pressure congruent with the gas sales line pressure. The resulting water, oil, and dissolved gases flow to a three phase separator, usually a heater treater, to separate all three phases at a lower pressure. The resulting oil and water

flow to tank storage. If connected to a pipeline, a lease automatic custody transfer (LACT) unit controls the shipping of the crude oil from the facility. Otherwise, oil is transferred from the tanks to truck. A typical facility is provided in Figure *1*. Heater-treaters shown in Figure *1* include both vertical and horizontal types. Residence time is typically shorter in vertical treaters.

Figure 1: Typical oil and gas production facilities in Bakken

Other configurations of separation equipment are possible which include test treaters, vapor recovery systems, and comingled conditioning systems. Applications are evolving as multi-well pads continue development. However, currently the system provided in Figure *1* is the most common at the present time.

3   Process modeling and simulations methodology

This chapter covers details related to the software used for the process modeling, the thermodynamic considerations established in the simulations, the vapor pressure output from the model, the process flow diagram for the simulations and the process model base case and assumptions.

3.1   Software

During this study, the project team used Honeywell's UniSim® Design Suite R443 tool for modeling and simulation purposes. Honeywell's UniSim® Design Suite is a process modeling software that provides steady state and dynamic process simulation in an integrated environment as shown in Figure *2*. It provides tools to help engineers evolve process optimization designs with lower project risks, prior to committing to capital expenditures (Honeywell, 2016).

Major use cases in process modeling using UniSim® Design Suite include:
- Process flowsheet development
- Utilizing case scenarios tool to optimize designs
- Equipment rating across a broad range of operating conditions
- Evaluating the effect of feed changes, upsets and alternate operations (Honeywell, 2016)

Figure 2: Honeywell's UniSim® Design Suite Simulation Environment *(Honeywell, 2016)*

3.2   Thermodynamic considerations

The fluid package in Honeywell's UniSim® Design Suite contains all the necessary information for pure component flash and physical property calculations. The fluid package chosen for this study was Peng-Robinson.

The Peng-Robinson (PR) Equation of State (EoS) was developed in 1976 at The University of Alberta by Ding-Yu Peng and Donald Robinson in order to satisfy the following goals:
1. The parameters should be expressible in terms of the critical properties and the acentric factor.
2. The model should provide reasonable accuracy near the critical point, particularly for calculations of the compressibility factor and liquid density.
3. The mixing rules should not employ more than a single binary interaction parameter, which should be independent of temperature pressure and composition.
4. The equation should be applicable to all calculations of all fluid properties in natural gas processes (Peng & Robinson, 1976).

The PR EoS is described as follows:

$$p = \frac{RT}{V_m - b} - \frac{a\,\alpha}{V_m^2 + 2bV_m - b^2}$$

$$a = \frac{0.45724\,R^2\,T_c^2}{p_c}$$

$$b = \frac{0.07780\,R\,T_c}{p_c}$$

$$\alpha = \left(1 + \kappa\left(1 - T_r^{0.5}\right)\right)^2$$

$$\kappa = 0.37464 + 1.54226\,\omega - 0.26992\,\omega^2$$

$$T_r = \frac{T}{T_c}$$

where ω is the acentric factor of the species, R is the universal gas constant, Tc is the critical temperature of the species and Pc is the critical pressure of the species (Peng & Robinson, 1976).

The PR EoS has become the most popular equation of state used in the petroleum industry. For the most part, the PR EoS exhibits performance similar to the Soave-Redlich-Kwong (SRK) EoS, although PR EoS is generally superior preferred in predicting fluid behavior at the critical point. A slightly better performance around critical conditions makes the PR EoS better suited to gas/condensate systems (Donnez, 2007).

3.3   Vapor pressure

Vapor pressure is defined as the pressure exerted by a vapor in thermodynamic equilibrium with its condensed phases (solid or liquid) at a given temperature in a closed system. The equilibrium vapor pressure is an indication of a liquid's evaporation rate. It relates to the tendency of particles to escape from the liquid (or a solid). A substance with a high vapor pressure at normal temperatures is often referred to as volatile.

The following vapor pressure (VP) values can be extracted directly as an output from Honeywell's UniSim® Design Suite R443:

Reid VP at 37.8 C
The ASTM D323-08 method is used for the calculation of the Reid VP at 37.8 C. It is defined at the pressure at which 80% of the stream by volume is vapor at 100°F (37.8°C). In UniSim Design, this

pressure is determined by iterative flashing of the fluid. This calculation is always done on a dry basis (i.e. any water content of the stream is ignored) and always uses the legacy HYSIM Flash.

ASTM D323-73/79

This correlation is also known as P323. The pressure is adjusted at the Reid VP reference temperature until the vapor to liquid ratio is 4:1 by volume. This correlation is essentially the same as the Reid VP at 37.8 C correlation, except it is not on a dry basis and the flash method used is the same for the rest of the flowsheet.

ASTM D323-82

Liquid hydrocarbon is saturated with air at 33°F and 1 atm pressure. Since the lab procedure does not specify that the test chamber is dry, the air used to saturate the hydrocarbon is assumed to be saturated with water. This air-saturated hydrocarbon is then mixed with dry air in a 4:1 volume ratio and flashed at the Reid VP reference temperature, such that the total volume is constant (since the experimental procedure uses a sealed bomb). The gauge pressure of the resulting mixture is then reported as the Reid VP.

API 5B1.2

This property correlation is generally used for condensate and crude oil systems (typically wide boiling preprocessed hydrocarbons). True VP is correlated against Reid VP and the temperature. This property solves the API databook equation of the correlation for Reid VP. The correlation is based on data from 1959, but it is popular with engineers for its quick calculations (Honeywell, 2009).

All vapor pressure simulation results presented in this study are obtained from the Reid VP at 37.8 C output calculated using the ASTM D323-08 method.

3.4 Process flow diagram

The process flow diagram simulated in this study is presented in Figure *3*. The process consists of the fluid flowing from the wellhead to a two-phase separator. The gas and liquid are separated by gravity in a high pressure separator. The separator can be either horizontal or vertical. The gas leaving the top of the separator is sent to the sales pipeline. The liquid leaving the bottom of the separator is sent to a second stage separation. This liquid enters a heater treater for further separation by thermal treatment. The gas exiting the heater treater is often times flared; and the crude and water are sent to storage, respectively. From the storage, the crude is sent to the lease automatic custody transfer for sales.
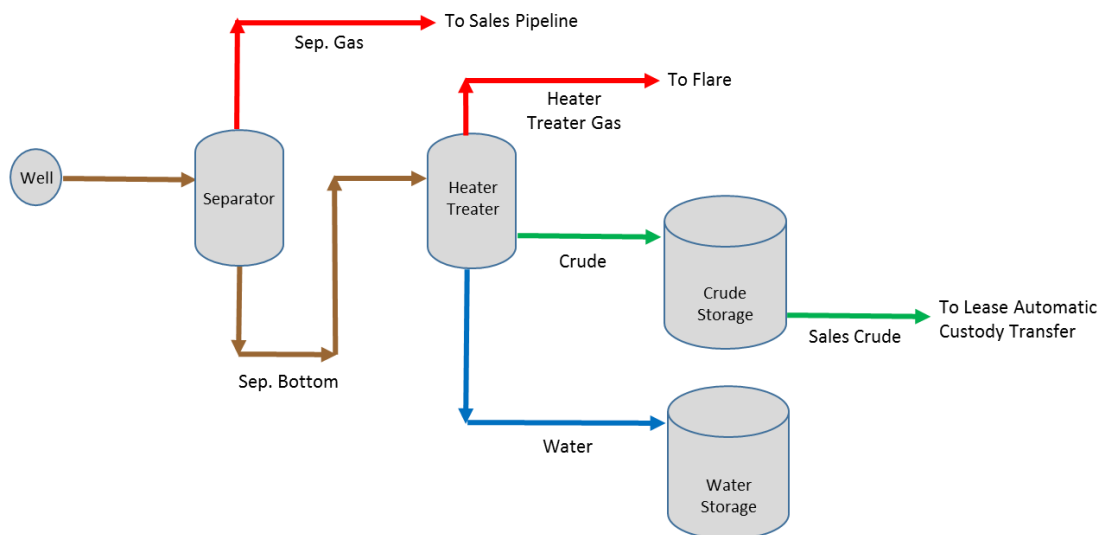
Figure 3: Simplified process flow diagram for this study

The majority of Statoil's Bakken facilities follow the process flow diagram described above. Therefore, this case was chosen for the modeling and simulations in this study. In Figure 4, the simulation environment in UniSim® Design is presented.
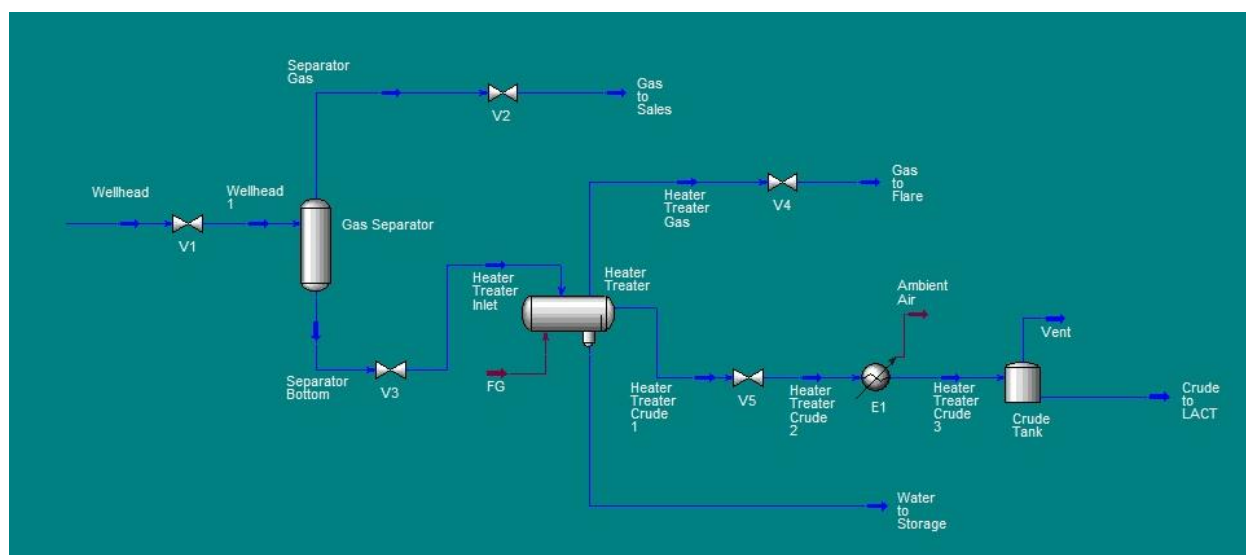

Figure 4: Honeywell's UniSim® Design Suite simulation environment for this study

3.5   Base case and assumptions

The parameters presented in Table 1 represent the base case for this study. In addition, the following assumptions were made for the process simulations:
- Steady-state model performing mass and energy balance of a stationary process (a process in an equilibrium state)
- Flows are actual volumes at operating conditions
- No heat loss over process equipment or tubing.

Table 1: Base case parameters for process simulations

Process parameter	Base case value
Separator pressure (psi)	90
Separator Temperature (°F)	96
Heater treater pressure (psi)	20
Heater treater temperature (°F)	120
Crude flow to sales (bbld)	95
Gas flow to sales (mcfd)	90
Gas flow to flare (mcfd)	7

4   Analysis and sensitivities

The heater treater and separator were chosen as area of focus for the sensitivity analysis of this study. This choice was made due to the ability of adjusting operational parameters of these units in the field in order to control the vapor pressure of the crude leaving these conditioning equipment. In Figure *5*, the area of focus is highlighted.
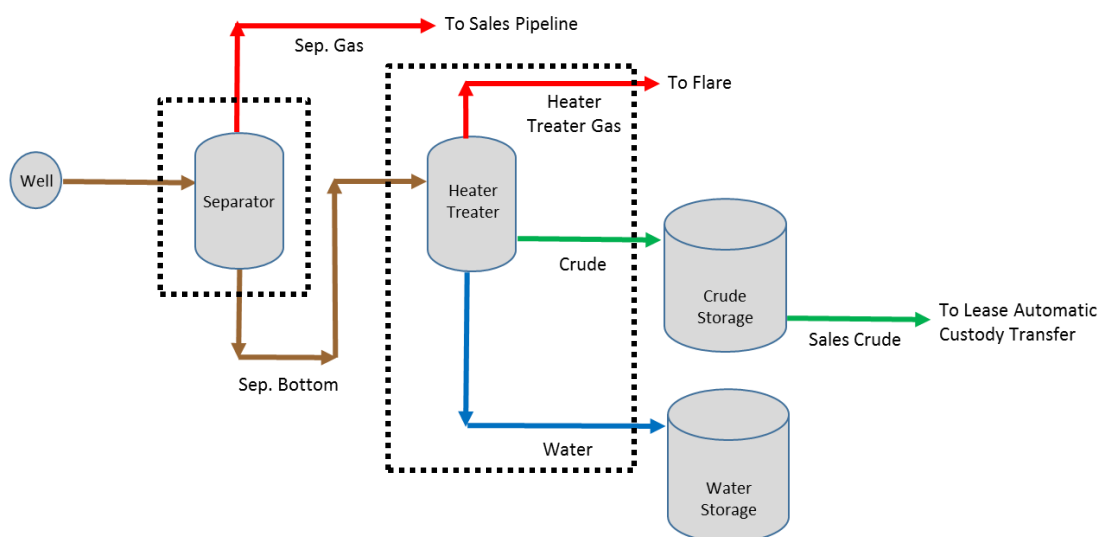

Figure 5: Area of focus for the process model sensitivities

4.1 Effect of heater treater pressure and temperature on crude vapor pressure

Sensitivities around the crude vapor pressure at the heater treater were established by varying the inlet pressure of the heater treater and the heater treater duty. The consequence was a variation of the heater treater pressure and temperature.

The effect of heater treater pressure and temperature on crude vapor pressure leaving the heater treater is shown in Figure 6.
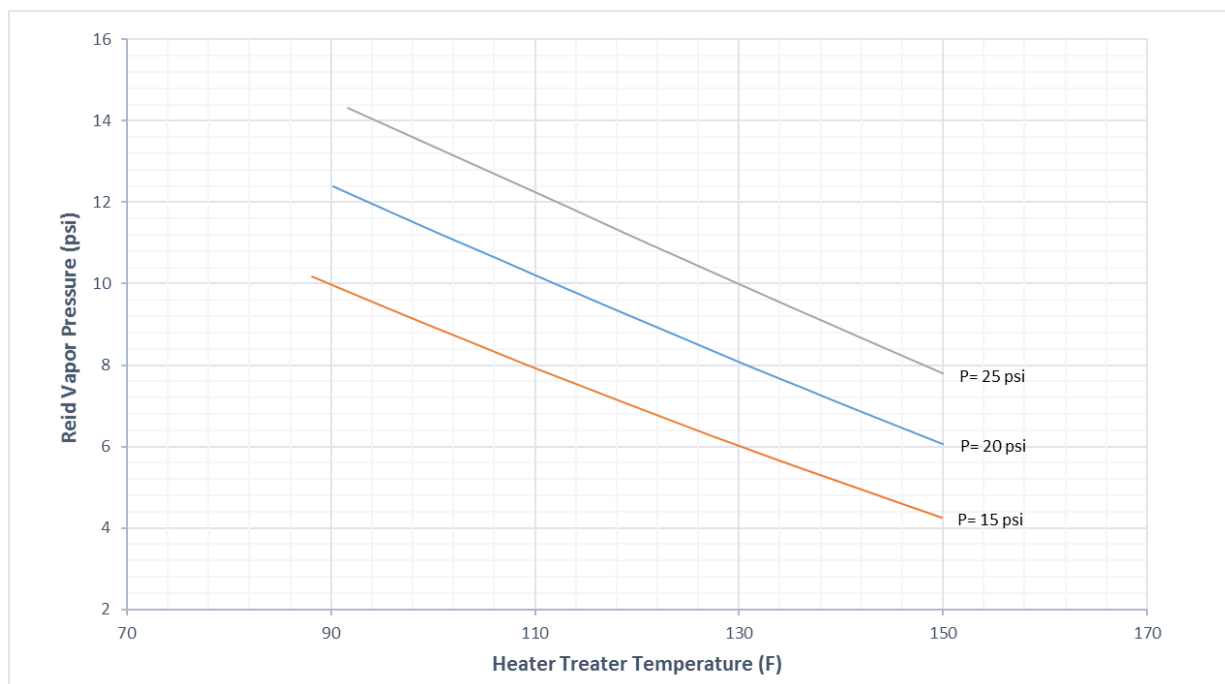

Figure 6: Effect of heater treater pressure and temperature on crude vapor pressure leaving the heater treater. (Pressure at the separator was set to 90 psi)

Figure 6 clearly shows how the heater treater pressure affects the vapor pressure of the crude exiting the equipment. As the heater treater operating pressure decreases from 25 to 15 psi, the vapor pressure of the crude decreases as well.

Figure 6 also shows how the heater treater temperature affects the vapor pressure of the crude exiting the equipment. As the temperature increases from 90 to 150°F, the vapor pressure of the crude decreases.

Sensitivity analyses around the heater treater pressure and temperature suggests that the heater treater pressure and temperature have a significant impact in crude vapor pressure. Results suggest that higher treater temperature and lower treater pressure result in reduced crude vapor pressure.

4.2   Effect of separator pressure on crude vapor pressure

Further sensitivities around the crude vapor pressure at the heater treater were established by varying the inlet pressure of the separator. The effect of separator pressure on crude vapor pressure leaving the heater treater is shown in Figure 7.
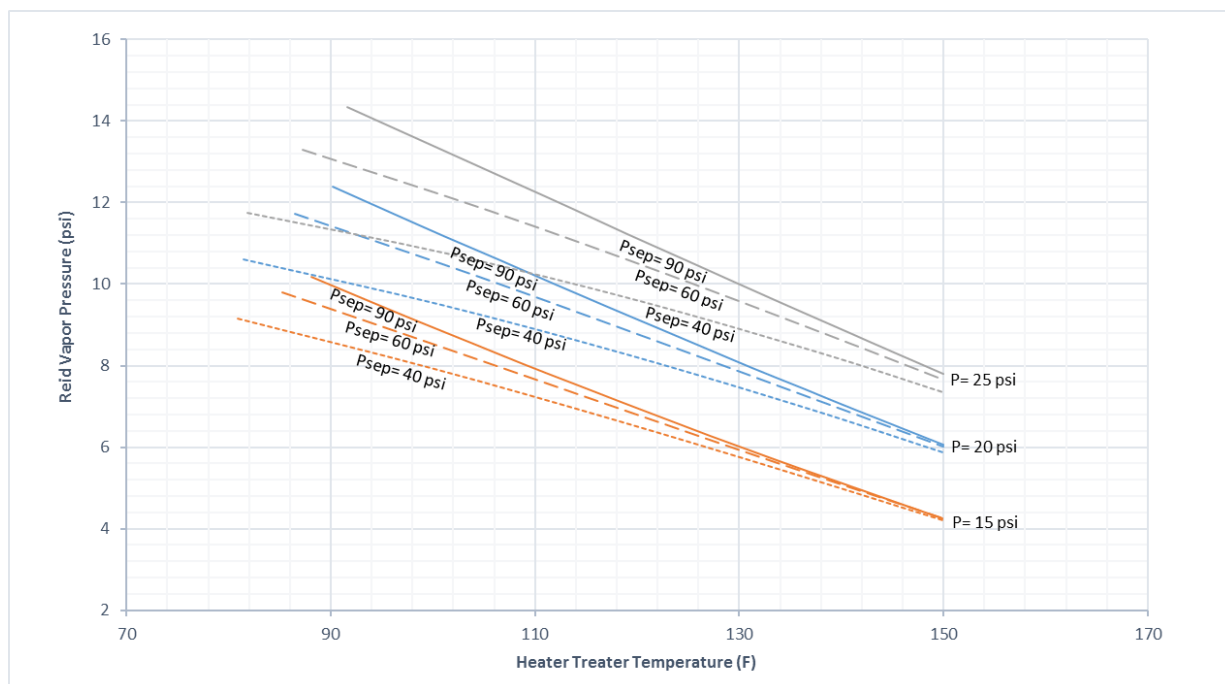

Figure 7: Effect of separator pressure on crude vapor pressure leaving the heater treater. The pressure at the separator was set to 40, 60 and 90 psi

Figure 7 shows how the pressure at the first stage of separation affects the vapor pressure of the crude exiting the heater treater. At lower heater treater temperatures (between 90 and 120°F), lower separator pressure yields lower crude vapor pressure. At higher heater treater temperatures (between 120 and 150°F), the separator pressure has no influence in the crude vapor pressure.

These observations can be applied in the field, specifically during the winter season. At colder ambient temperatures, the heat loss from heater treaters increase which makes more challenging to reach the higher temperatures in the heater treater. Based on these simulations results, it can be recommended to run the separator at lower pressure. For example, if a crude vapor pressure of 10 psi wants to be achieved out of a heater treater running at 25 psi;
- for a separation pressure of 40 psi, the heater treater only has to be fired at 114°F
- for a separation pressure of 60 psi, the heater treater has to be fired at 126°F
- for a separation pressure of 90 psi, the heater treater has to be fired at 130°F

5   Conclusion and further work

Modeling completed in this study suggests that heater treaters are adequate devices to control the vapor pressure of crude oil in North Dakota. A RVP of 5 to 14 psi for crude oil is possible over operating temperature ranges from 90 to 150°F, and pressure ranges from 15 to 25 psi. Inclement weather and cold conditions can limit the ability of heater treaters to achieve the temperatures necessary to meet transportation requirements for RVP. The current results establish a baseline from which to compare heater treater operation with field measurements of $VPCR_4$. Additional work is planned to validate the modeling results with field measurements and sampling of vapor pressure. Also, modeling work is expected to continue throughout the project as field technologies are applied, and measurements from tanks storage are completed.

The project team is presently testing a vapor pressure reduction unit in the field and collecting $VPCR_4$ measurements. The unit is intended to treat crude oil by conditioning and recycling the oil around the primary separator. The results will be included in subsequent reports, and will include $VPCR_4$ measurements at the primary separator, secondary conditioning, and after tank storage. Supporting modeling work will be included.

6   References

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